ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

COLLAGE OF ARCHITECTURE AND CIVILENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

GEOTECHNICAL CONSIDERATION IN TUNNEL DESIGN AND CONSTRUCTION METHOD

A CASE STUDY 0F TUNNEL T-02 OF THE AWASH – KOMBOLCHA – HARA GEBEYA RAIL WAY TRANSPORT PROJECT

FOR THE PARTIAL FULLFILLMENT OF THE DEGREE OF MASTER OF ENGINEERING IN GEOTECHNIAL ENGINEERING

BY:

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I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled "geotechnical consideration in tunnel design and construction method a case study 0f tunnel T-02 of the awash – kombolcha – haragebeya rail way transport project" in partial fulfillment of the requirement for the degree of Master of Engineering in Geotechnical Engineering.

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Abstract

Geotechnical investigation is important in civil engineering structural design and implementation. It is particularly crucial for tunnel design, estimation of tunnel excavation rate, costestimate, support requirement and stability.

Tunnel T-02 one of the tunnel lay Awash weldya rail way line has been kindly provided by ERC evaluated on the basis of theoretical knowledge and practical implication.

The result shows that determine all of physical and mechanical property of the rock mass along the tunnel line is important input for the design and implementation of the tunnel. However the most important factor that varied frequently and required intervention during tunneling is the RMR. The most dominant rock types is volcanic ideally. Under condition of no discontinuity it is the most string rock type that requires and expected to be stable with no or less support. However fractures and jointing have affected the rock in general and zonally very strongly. This factor reduced the RMR by 50 % more and hence required consideration support, throughout the tunnel. Duringtunneling, the geotechnical engineer was evaluating the RmR and corresponding requirement of the support in every 30m length of the tunnel. Finally the tunnel length required support which shows variation by 30% from the original design. This fact indicate that rock mass physical and mechanical properties are the most determinatefactors for tunnel design ,tunneling identification of support system as well as estimating of project life and finance.

1. Introduction

Tunnels are underground structures which are recognized as a means of attaining convenient transport through conditions posing natural difficulty or special hazards. Surmounting such naturalfeatures as mountainous terrain, rivers and other water body by tunnels allows safe and convenient transport at all times irrespective of weather conditions. According to Whittaker and Frith (1990), tunnels are major part of everyday life for the populations of most developed countries, and their service and general range of application are broadly categories as traffic tunnels, water conveyance tunnels and mining tunnels.

In tunnels, geological and geotechnical conditions which may result in decreased competence of the rocks surrounding the excavation often result in increasing tunneling difficulties and/or costs in addition to affecting operational and safety aspects. Consequently, in depth appreciation of the geological conditions plays an important role from the stages of design and planning, though to construction and eventual commissioning and operation of the tunnels. Many tunneling problems are caused by unexpected changes in the strength or deformability and other parameters of the rock mass where it is being excavated. When such a mass is disturbed, it undergoes distribution of stresses, often accompanied by a deformation of rock mass. These changes can be either inconsequential or catastrophic, depending on the distribution of stresses in the rock, its strength, deformability etc. Early assessment of such changes in tunneling projects can be of great importance in identifying potential unstable zones, and also in devising appropriate remedial measures (Kolymbas, 2005)

1.1 General back ground of tunneling

Rail way transportation is one of the important infrastructure facilities that are needed in the achievement of effective development and provides an efficient cost effective and environmental friendly transport system.Which can quickly haul large volumes of goods which are not easily transported through motor vehicles for larger distance. Now a days,

there is a high demand of railway transportation systems in the world including in Ethiopia for a long and short distance transport of passengers and goods

To fulfill these demands, many railway projects are launched in Ethiopia One ofthese projects is the construction of Awash - Kombolcha – Hara gebeya rail way project.

1.2 Railwayconstruction by Ethiopian Railway Corporation

The Ethiopian government has been under taking several transportation infrastructure projects since the 1st five year growth and transformation plan (GTP) which was launched in 2011 and successfully completed in 2015 and followed by the launches of GTP-2 in 2016. The projects aim at enhancing the transportation network within the country and also connecting to neighboring countries and ports. This is believed to facilitate the transpiration of people and goods to accelerate socio- economic growth and development. It is also believed to provide efficient mobility and improve the exports and import activities and boosting the economic development. National Railway Network of Ethiopia (NRNE) is one of the several projects which constitute inthe plan. (Seefigure 1.1)

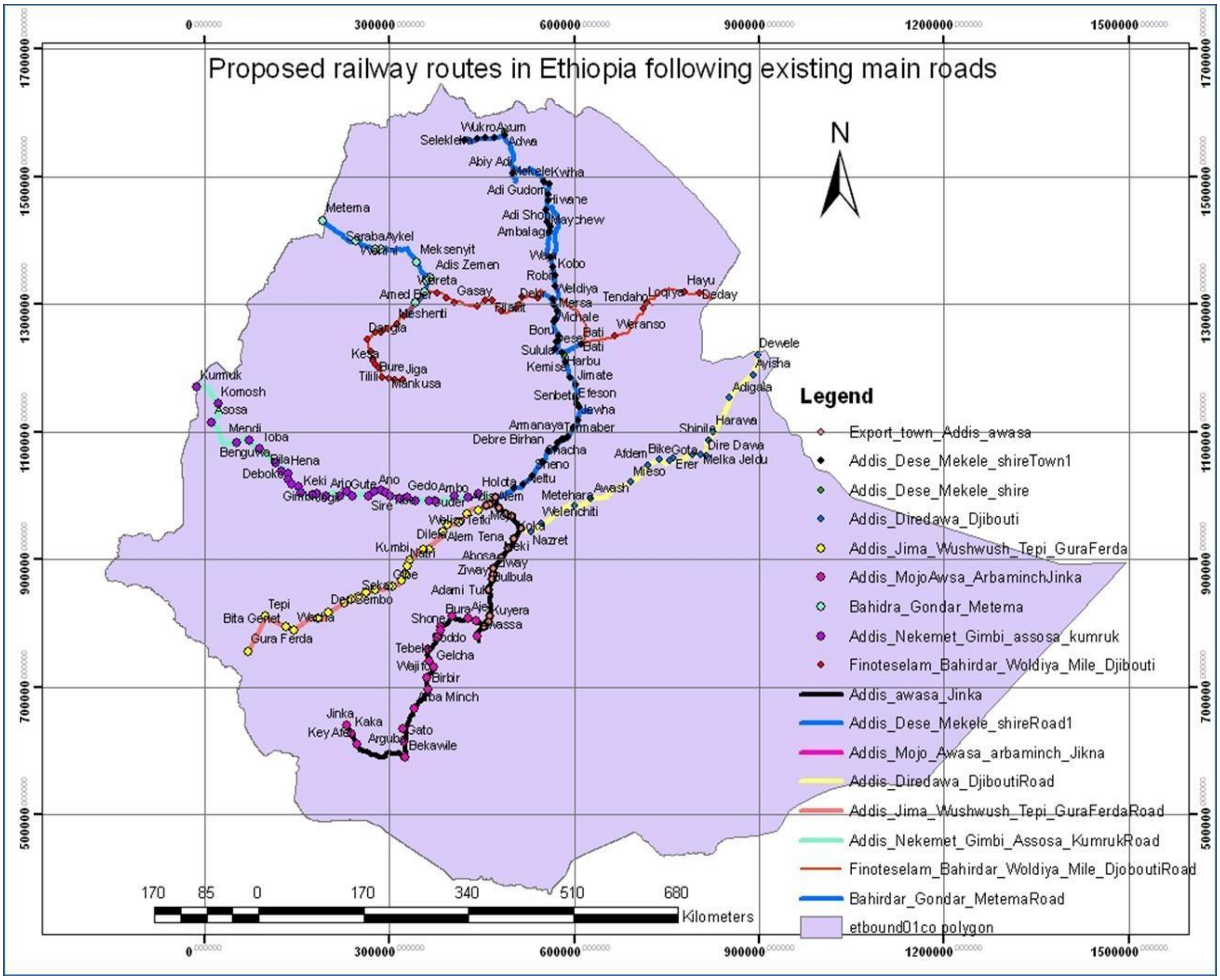


Figure 1.1 proposed railway routed in Ethiopia(Source: http://www.erc.gov.et)

The Awash Woldia / Hara Gebeya railway project is part of a railway project that will connect northern Ethiopia to Addis Ababa - Djibouti railway line at Awash station. Awash railway station lies along the railway line from Addis Ababa to Djibouti.

Addis Ababa - Djibouti is the primary transportation link for mobility of goods and people. The route is also used for import and export purposes through Djibouti port. The Awash – weldya railway project is approximately 390km-long singlelane railwayline starts from the north-east of Awash town and extends north wards through Kombolcha and Woldiato Mekele.

The construction of the route has two phases, the first phase covers the distance from Awash – Kombolcha – Hara gebeya and the second phase from weldya to mekele. (Figure 1.2)

Figure 1.2 EthiopiaRailwaycorporation Transit Route (Source: http://www.erc.gov.et/)

1.3 General over view of the project

Awash – Kombolcha – Hara gebeya rail way projects comprises the design and construction of a390 km long rail way between cities of Awash and Weldya .during routs selection eleven hills crossin this railway project (Refer figure 1.3 and figure 1.4)

According to the ERC,SpecialFeaturesand consideration oftheProjectinclude transporting long and short distance of passengers and goods,provision of alternative transportation system to the region other than transport vehicles and air transport, technology transformation during construction as it is being built by foreign construction company. More over as it is electric power rail system, it is design to reduce carbon dioxide emission,i.e. environmentally friendlyproject.

The project design and construction is being undertaken by Yapi Markezi at total estimated cost of 37 billion Ethiopian birr. The project commenced on February 2015 and executed to complete on February 2017 (source Ethiopian rail Way Corporation).

1.4. General objectives of the study

the objective of this project study is to evaluate the geotechnical consideration in tunnel designand construction along the alignment of Tunnel number T-02 located around Kombolcha, some 150km from Awash. This will include evaluation ofgeological map, geo-structural surveying, rock mass classifications, and determined of rock properties which were made available by the ERC and understand. The project study is believedto enhance the theoretical understanding through. The application of practical project work through the appraisal of a 188 m long tunnel.

1.5. Specific objectives of the study

To meet the aforementioned objectives, the following specific objectives wereformulated;

- ✓ Study the geological features and mechanical properties of rocks encountered and recorded by ERC project influenced of geotechnical data on tunnel design and construction along the tunnel alignment.
- ✓ Study identify geological problems that affect the construction of tunnels in the project area.
- ✓ Study and analyzean engineering geological evaluation on the site investigation results.
- ✓ produced relevant geotechnical parameters for the underground design purpose and

- ✓ Comparing the design and implemented tunnel and recommendations based on the actual work practice of tunnel construction and effect of geotechnical parameters.

1.6. Approach and methodology

To accomplish the objective of the project study the following methodology has been followed

1. Preparation of short summery of geotechnical consideration for tunneling (theoretical approach).
2. Collection of relevant data of tunnel T-02 from Ethiopian rail way corporation
3. Evaluation of the data with respect to the theory of geotechnical investigation for tunnels.
4. Drawing conclusion and recommendation from the study.

CHAPTER TWO

2.General theory of geotechnical studies for tunneling

2.1. Introduction

Tunnels are long linear undertaking with few opportunities to perform the work at more than one location. Tunnels are also a series of repetitive operations each of which usually must be finished before the next can be started. Tunnel are built for transport of people, cars, trains and water, for storage and for mining. They may be deep or shallow, in rock or in soil, in urban or in rural environments. They may be built by boring or by cut and cover methods or by sinking them into the bed of a river.

The geotechnical property in design of tunnels includes site investigation, ground probing and in-situ monitoring, as well as the analysis of stresses and deformation.

2.2. General requirements and procedure in geotechnical consideration for tunneling

Planning a tunneling project requires the interdependent participation of the following disciplines, at a minimum:

Geologist, Geotechnical engineer, Excavation technologist, Designer of supporting structural elements, including long –term behaviorof materials and Contract principle and law.

Although the experts in each of these disciplines may be responsible only for their specific area of knowledge, the decision on the main design features should be the outcome of the cooperative integration of all the discipline.

The basic documents for tunnel works should include:

- The geological report presenting the results of the geological and geophysical survey.
- The hydrogeological report.
- The geotechnical report on site investigation.
- Including the interpretation of results of site and laboratory tests with respect to the tunneling process, soil and rock classification.

- Information on line, cross section, drainage and structural elements affecting later of the tunnel.
- Planefor and a description of the projected excavation or driving procedure, including the different cross- sections related to different ground conditions.
- Design document for the types of excavation methods and tunnels supports likely to be applied.
- The program for the in situ monitoring of the tunnel by field measurements.
- The analysis of stresses and deformation and (for unlined tunnels as well as for single or double lined tunnel) and the dimensioning of the tunnel support for intermediate phases and final linings.
- The design of water proofing or drainage.
- Structural documents for the final design of the tunnel project including the detailing.
- During and after excavation, reports on the field measurement and interpretation of their results with respect to the response of the ground and the structural safety of the tunnel.
- Documentation of the problems encountered during the excavation and measures applied.

The above sequence of these basic documents also provides the general outline of the design procedure.

2.3Geological investigation and geotechnical interpretation for underground works

An important question which requires careful consideration at the start of any underground excavation project is: What constitutes a realistic site investigation for that project and to what extent can such a site investigation be expected to minimize the unknowns which could give rise to tunneling problems and consequent contractual difficulties?

The prime purpose of any tunnel site investigation should be to obtain the maximum amount of information on rock characteristics, structural systems and groundwater conditions. This information is important to the tunnel designer in that it should enable one to anticipate the behavior of the rock surrounding the tunnel and the type of support required to maintain the tunnel in a stable condition. The information is also important to the contractor in that it should provide him with a basis for establishing the optimum tunneling method and the type of services which he will require in order to meet the construction schedules.

The first fact which must be recognized when planning a site investigation program for a tunnel is that there is no such thing as a standard tunnel site investigation. Consider, the amount of previously available information and the information likely to be obtained from any site investigation differs by orders of magnitude in these two cases. In addition the amount of time and money allocated to one site investigation may differ so much from that of another that there is no hope that the end results will be comparable. Consequently, each site investigation program must be carefully tailored to the specific site conditions, end results required and amounts of time and money available.

The linear extent of a tunnel means that it will probably traverse a greater variety of geological conditions than would be encountered in the excavations or foundations for most other engineering structures. Consequently, very careful consideration must be given to the amount of information which can be accumulated from a site investigation program and the accuracy of the projections which can be made from this information.

2.4. Determination of geotechnical properties of rock tunneling

Quite a number of geotechnical properties of the rock are required to be determined to assess the suitability of the area for tunneling; to assess the stability of the tunnel for the intended purpose and duration; to assess the support requirement to ensure stability of the tunnel walls and roof.

The most important properties to be determined include; among others,

- The geological material and its physical and mechanical properties.
- Compressive and shear strength of the geological material which is usually determine either from intact rock sample in laboratory or strength of rock mass (as measured in natural field condition)
- Factors affecting the strength of the rock mass including geological structures; (discontinuities and other physical properties of geological structures).
- Ground water condition and
- Insitu stress measurement.

2.4.1. Rock mass classification

Rock units in the tunneling area need to be classified based on their physical and mechanical properties. A number of empirical classification approaches have been developed by researcher over decades.

The Empirical methods are based on assessment of precedent practice and generally have a successful track record in rock tunnels. Ideally the support recommendations have been 'calibrated' against actual performance for a wide range of tunneling conditions and tunnel sizes. Some soft ground empirical rules have also been established but these tend to be based on local experience rather than being universally applicable.

The empirical development methods of rock mass classification are useful because they Identify the most important parameters influencing the rock mass, divide a rock mass formation in to groups of similar behavior, provide a basis for understanding the characteristics of each rock mass class, relate experiences of rock conditions at one site to those at another, Derive quantitative data and guidelines for engineering design and provide a common basis for communication between geologists and engineers.

The most frequently used empirical methods of classifying rock mass are geological strength index (Hock and Marionon Zool), Rock Quality Designation index (RQD) which was developed by Deers et.al (1967) , rock structure rating (RSR) developed by Wickham et.al (1972) and geomechanical classifications or Rock mass rating (RMR) by Bieniawski (1976)

Of these the geomechanics (RmR) method introduced by Bieniawski (1976) is the most effective and widely used for geotechnical classification and consideration for underground tunneling.

The empirical approach, based on rock mass classifications is the most popular probably because of its basic purpose of simplicity and ability to managing uncertainties. The geological and geotechnical uncertainties can be tackled effectively using proper rock mass classifications.

The RMR rating used the following parameters

I. Uniaxial compressive strength of rock material.
II. Rock quality designation (RQD)
III. Spacing of discontinuities**.**
IV. Condition of discontinuities.
V. Ground water conditions.
VI. Orientation of discontinuities.

Based on these five main parameters, the rock at tunneling can ready be classified and the required support system can be determined.

Accordingly major input for tunnel designs, support requirements and types are obtained from the RMR method of classification. The classification also guides tunnel excavation method, choice of TBM type, the result from RMR classification further contributes significantly in tunnel rate, planning (time and budget estimation).

CHAPTER THREE

3. Awash weldya railway tunnel project (Tunnel T-02)

3.1. Geological settingand geotechnical investigation around t-02 area

in this railway route, four major groups of lithostartigraphic units are encountered. These are

- Eocene volcanic
- Oligocene –Miocenevolcanic
- Upper Miocene volcanic
- Quaternary volcanic

Which are overlain on the plains and sometimes on the slopes, by associated quaternary deposits of lacustrine, fluvial and slopes debris origin

Geological units along tunnel T-02 is mainly characterized by upper Miocene Rhyolite termed kemisie Rhyolite with same basalt in the vicinity. The rock unit was described to be weak as it is affected by NE and ENE faults, two of which cut the proposed line of the rail way tunnel (Refer figure 3.1)

The geological map and the cross section of the tunnel T-02 site and vicinity are given below

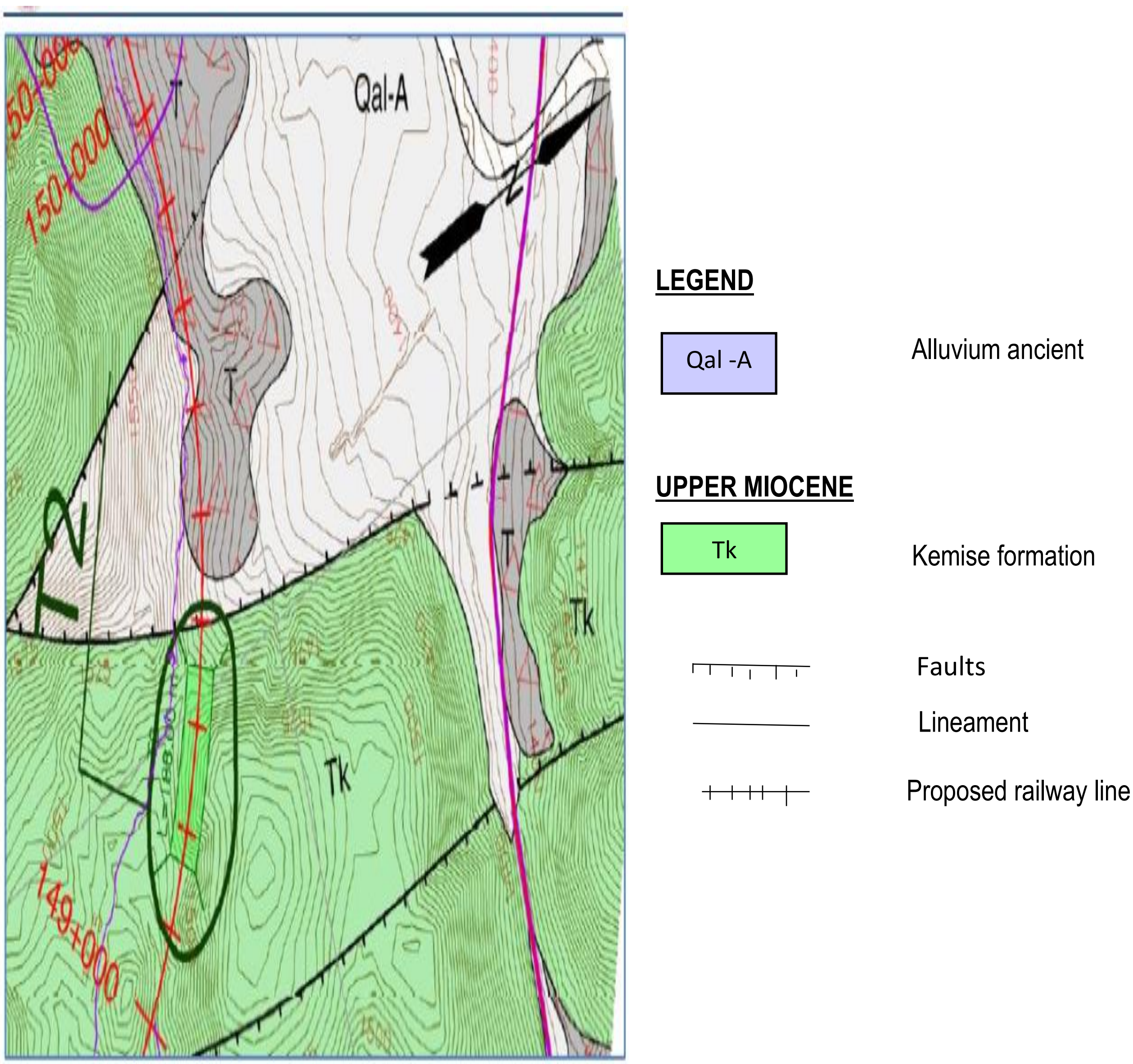


Figure 3.1geological map of T-02 site and vicinity

(Source: ERC and AWH railway project office)

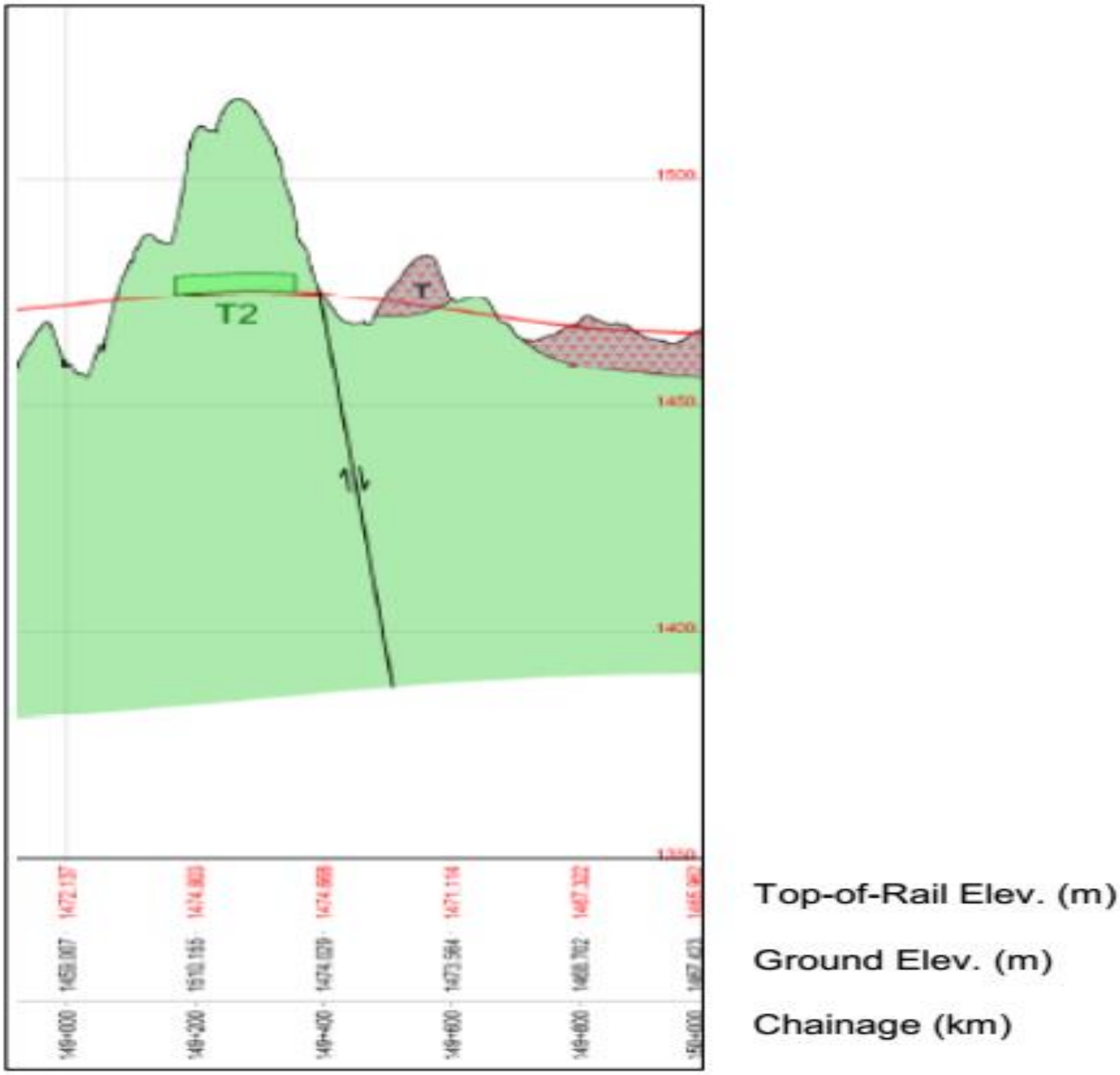


Figure 3.2 geological profile of T-02 site and vicinity

(Source: ERC and AWH railway project office)

The geological map and section above are based on preliminary mapping on the area. It has been supplemented by borehole datafor finaluse (reference; ERC). However, the tunnel wasderived entirely in rock, as shown. (For a more detailed section see appendix 1)

3.2. Sub surface investigation

Data of sub surface investigate at the tunnel site has also been obtained from ERC. The subsurface investigation comprise of soil investigation boring, field tests and geophysics surveys, as well as laboratory testing on samples recovered from bore holes used to determine the site ground characteristics.

The data included five bore hole data range in depth from 20 -50mt's field water pressure testing data from the four of five bore holes using lugeon methods, four seismic refraction survey across the tunnel axis, each 48m long spread with 4.5Hz geophones and 2m centers (18 kg hammer was used as energy source). the results of which should that the p and s waves velocity locally reached and exceed 2500m/s ,1600 m/s respectively .

The data also included geotechnical laboratory test results of selected samples. The data comprised of unit weight , unconfined compressive strength , modulus of elasticity , poison's ratio and point load index test of samples .(for details of the geotechnical test results, please refer appendix4.)

3.3 Soil profile and ground modeling

As described above, the site for T- 02 is characterized by volcanic rocks, mainly rhyolite (kemise formation (TK), Glassy basalt and trachybasalt units have also been encountered on the surface.however, the rock unit at the tunnel level is expected to be exclusively rhyolite (Appendix 1).

In general the rock encountered in the boreholes is very weak to weak, locally moderately strong to strong. On the hand, joint frequency is locally variable. In fact, it has been possible to delineate two main zones, based on RQD.

No ground water has been encountered in the bore hole drilled for this tunnel. Geomorphological attitude of the tunnel rules out possibility of rising of the ground water level in the rainy season. However, local seepage from the surface may occur after prolonged periods of precipitation.

Based on the findings of the investigation, it can be concluded that the ground conditions along Tunnel T-02 can be modeled with very weak to moderately strong rhyolite, characterized by zones based on discontinuity intensity (for details ,see appendix 1) (source from AKH Railway Project).

CHAPTER FOUR

4. GROUND PROPERTIES AND GEOTECHNICALPARAMETERSFOR TUNNEL T-02 DESIGN

4.1 Derivation of geotechnical parameters

Classification of rock is made on the basis of geological strength index, GSI. GSI is related to RMR (rock mass rating) but the latter is more difficult to determine with borehole information. GSI allows more comprehensive engineering judgment also utilizing data from seismic surveys and engineering geological observations on the surface. For the strength of the intact rock, unconfined compression and point load index tests are carried out.

The modulus of elasticity is either tested directly in the laboratory or determined from the uniaxial compressive strength and the modulus ratio, which depends on the lithology and estimating the disturbance factor by Hoek et.al.(2002).Engineering judgment is also used to select the characteristic parameters.

4.1.1 Design evaluations and geotechnical parameters

Tunnel T-02 was designed with the assumption that it will be driven entirely in rock. The south and north portal excavations was also be carried out in rock. A thin layer of colluvium locally involved in the north portal excavation was considered to be completely removed during site preparations and had no other effect on design.

Based on evaluation of the borehole logs and seismic survey results, the geotechnical model and rock mass parameters were proposed for the site Tunnel T-02, with the assumption that there is no ground water expected in this tunnel. However, it was assumed that local seepage may occur especially in the rainy seasonas the rock mass in intensity jointed.

It is mechanical excavation at the portal areas (south portal was require ripping and some blasting).Advancement in the tunnel would be by blasting and mechanical excavation.

Based on the modified GSI classification. The geological strength index has been taken as GSI =20to 65% for rhyolite with very closely spaced joints (RQD<<50%) to that with

RQD>50% also considering joint surface conditions. Estimate of characteristic unconfined strength have been assigned to several zones differentiated for design purpose along the tunnel.

Table 4.1. Tunnel zones and ground descriptions (source ERC and AWH railway project office)

Zone	Ground type	Intact rock strength, σ_{ci}	Typical overburden, H	Approximate Chain age (km)	Description
South portal	Rhyolite* GSI=20 upper layer / GSI= 25 lower layer	20 mpa	-	149+075-149+167	Rhyolite: weak to medium strong (locally very weak), moderately to highly weathered, with very closely spaced joints. RQD <<50%. No ground water
1	Rhyolite* GSI=25 (Tunnel body)	5 mpa	15 m	149+167-149+180	Rhyolite: weak to medium strong (locally very weak), moderately to highly weathered, with very closely spaced joints. RQD <<50%. No ground water
2	Rhyolite* GSI=35 (Tunnel body)	10 mpa	30 m	149+180-149+210	Rhyolite: weak (locally very weak or medium strong to strong), moderately to highly weathered, RQD >50%. No ground water
3	Rhyolite* GSI=25 (Tunnel body)	10 mpa	30 m	149+210-149+235	Rhyolite: weak (locally very weak or medium strong to strong), moderately to highly weathered, RQD >50%. No ground water
4	Rhyolite* GSI= 45 (Tunnel body)	15 mpa	35 m	149+235-149+255	Rhyolite: weak (locally very weak or medium strong to strong), moderately to highly weathered, RQD >50%. No ground water

Zone	Ground type	Intact rock strength, σ_{ci}	Typical overburden , H	Approximate Chain age (km)	Description
5	Rhyolite* GSI=65 (Tunnel body)	15 mpa	35m	149+255- 149+265	Rhyolite: weak (locally very weak or medium strong to strong), moderately to highly weathered, RQD >50%. No ground water
6	Rhyolite* GSI=45 (Tunnel body)	15 mpa	35 m	149+265- 149+295	Rhyolite: weak (locally very weak or medium strong to strong), moderately to highly weathered. RQD >50%. No ground water
7	Rhyolite* GSI=25 (Tunnel body)	15 mpa	15 m / 30 m	149+295 - 149+354	Rhyolite: weak (locally very weak or medium strong to strong), moderately to highly weathered. RQD >50%. No ground water
North portal	Rhyolite* GSI=25upper layer / GSI=35 lower layer	15 mpaupper layer / 20 mpalower layer	-	149+354 - 149+375	Rhyolite: weak to medium strong (locally very weak), moderately to highly weathered, with very closely spaced joints. RQD <<50%. No ground water

4.1.2 Seismic design parameters

The seismicity of the railway rout was already studied at the basic design stage. The current Ethiopian code for seismic design, EBCS-8 (1995) specifies a peak ground acceleration value,PGA=0.10

(For details see appendix 3.seismicity of the Horn of Africa)

4.2 The proposed design of T-02

Awash -kombolcha – Hara gebeya railway project is one line railway system. Due to consideration of volume traffic in the estimated rail way life and economic aspect.

The function of Tunnel T-02 are used for transportation purpose. The type of tunnel is house shoe, width of tunnel is8.3m and height of the tunnel is 9.2m. The expected design speed of rail is 120 km/h for passenger, 80km/h for custom dissertation writing service freight and 90 km/h at section with rough topography.

Tunnel support and excavation guided according to Beiniawskis' rock mass rating system. Tunnel T-02 excavation method is new Austrian tunneling method. Consideration of NATM are mobilization period less, effective in short distance tunnel, excavate in deferent shape and mucking of excavation material simple. Tunnel catting rat greater than 25 m^3 /h when RMR value less than 50 mpa (after Fowell and Johnson 1991). After the tunnel formed by mechanical excavation process , the newly formed tunnel surface is expected to line with full face in situ concrete lining to stabilize the exposed soil or rock faces.

Excavation rate was estimated from 2.2m upto 4.1 m per day

4.3 The implementation of T-02 tunnel design

Under listed information are taken from ERC

- ✓ There is change in shape and size in excavation stage. Because over blasting or over excavation.
- ✓ There is no change in shape and size after lining.
- ✓ In the case of hard rock ,thirty present of the total was Change in support system
- ✓ No change in choice of excavation machinery.
- ✓ No change in proposed construction method.
- ✓ actual excavation rate is 1 m length per day ,to continue supporting system

- ✓ Actual rids space every 1 m.
- ✓ No ground water during construction but remedial measure was taken in the case of rainy season

4.4 The variation between the design and final construction

Most of the assumed design input area fined out to be realistic .The variation between design and construction encountered due to local changes in physical and mechanical properties of rocks. Geotechnical behavior of underground tunnel line, that is to say during design proposed underground behavior are assumed as weak to medium strong, moderately to highly weathered, with very closed spaced joint with RMR >< 50, as a result it was proposed to fully support the length of tunnel by in situ concrete lining with ribs but during implementation the geotechnical team encountered thirty percent of actual underground rock was classified as good or very good with RMR > 61-81. therefore 30% of the tunnel length does not require support

The Implication of the variation between design and implementation for geotechnical consideration

Geotechnical investigations was carefully planned to take into account the significance of geology as well as the vast uncertainty associated with underground design and construction. The actual geotechnical information is obtained and evaluated the greater the potential for optimization of the alignment and profile and for greater cost saving.

In the Tunnel T-02 project , geotechnical engineer was guides construction activity by analyzing rock behavior per day, excavation rate , lining system and also supporting system for stability as well as cost effective . This is because samples taken from bore hole may not represent the characteristics of the rock mass of the project area. The implication of this is clearly observed and as a result of close monitoring of the geotechnical properties it is found out to be 30 % of the tunnel length did not require any support . This significant amount of finance.

CHAPTER FIVE

5. Conclusion and Recommendations

5.1 Conclusions

The geology along a tunnel alignment plays a dominant role in many of the major decisions that must be made in planning, designing, and constructing a tunnel. Geotechnical services, data collection, and evaluation should begin very early in the conceptual planning of any project and should continue through construction and even after construction to document the as-built conditions and the behavior of the tunnel in service.

The Awash- weldya tunnel project are ongoing construction project. Under this project tunnel T-02 wascompleted. Five representative borehole was determine to classify the underground condition by using geological and geotechnical parameter. The project Site investigation report shows that underground rocktypes are Rhyolite, Basalt and Trachybasalt. Its quality has been weak to medium strong, moderately to highly weathered with closely spaced joint.

During construction underground rock condition was the same as above classification limits. But the five borehole sample was not represent the all tunnel T-02 project. Contractor (Yapi Markezi) and other project team worker improve actual site ground condition by using Palmstrom (1982) and for these the RMR of the rock using Bieniawski.

No ground water condition present during siteinvestigation but on rainy season local seepage was expected to occur as the rock mass is heavily jointed.They have used water collecting perforated material, water proofing material around tunnel and surface water collecting ditch.

The construction method of this tunnel project are depend on rock mass classification, strength of rock material, length and shape of tunnel. According to Bieniawski (1976) tunnel excavation and support guidelines, Tunnel T-02 project excavation was used drill and blast and mechanical excavation. In this tunnel project excavation techniqueused is New Austrian tunneling method (NATM). NATM method was preferable than TBM and Road header due to short distance tunnel project; Mobilization period are minimum, Economical from other method, Excavation cost are minimum and step wise also fulfill therequiredshapes and Mucking out of excavated material is simple.

In this project the RMR value << 50; thestandup time was provide one hour for full face lining. Due to the RMR value are very good no lining was required. In the case of very good RMR value there is no need of permanent support. Even if during design stage the tunnel support system as full lining butThirty percent of the total Tunnel T-02 project was not construct by permanent support lining. But at mid span of this tunnel T-02 project; unnecessary one meter depth at crown and side of tunnel wallwas overblasted. The contractor and designer party was maintain over excavation by full face permanent lining.

5.2. Recommendations

Except for a probably < 5m thick collegial soil cover only in the north portal area the ground profile for tunnel T-02 consists entirely of volcanic rock. The rock is rhyolite. Basalt and trachybasalt are also present as out crops in thee overburden but are not of major concern in terms of the tunnel design.

No major excavation and stability problems was expected as long as the site crew is ready to takeaction in case of changes in the ground requiring immediate support. But at mid span of the tunnel has been done by work man ship mistake. Such like mistake should be avoided in the future because of economical wastage. Caremust be taken during excavation, as fault zones may pose threats to stability.

Tunnel construction is very challenging and full of risks. Thus, in Ethiopia technically skilled and experienced persons shall participate in the tunnel design and construction processes because the geological and geotechnical uncertainties can be tackled effectively using proper rock classifications on site.

Reference

- Bieniawski, Z. T. (1976). Rock mass classification in rock engineering. Proceedings of the Symposium on Exploration for Rock Engineering.
- BieniawskiZ. T. (1989)Engineering Rock Mass rating
- Deere, et.al. 1967. Rock quality designation index (RQD)
- Hara, A., Ohta, T., Niwa, M., Tanaka, S., and Banno, T. (1974). "Shear Modulus and Shear
- Hock and marionon zool
- Hoek, E., Carranza-Torres, C. and Corkum, B. (2002). Hoek-Brown Failure Criterion – 2002
- Hoek, E., Carter, T. G., and Diedrichs, M. S. (2013). "Quantification of the Geological Strength
- Hoek, E., Diederichs, M. S. (2006). "Empirical Estimation of Rock Mass Modulus" International

  Index Chart", 47th U. S.
- Journal of Rock Mechanics and Mining Sciences, London.
- Kolymbas, 2005
- Marinos, P., Hoek, E. (2000). "GSI: A Geologically Friendly Tool for Rock Mass Strength
- Palmstro , 1982

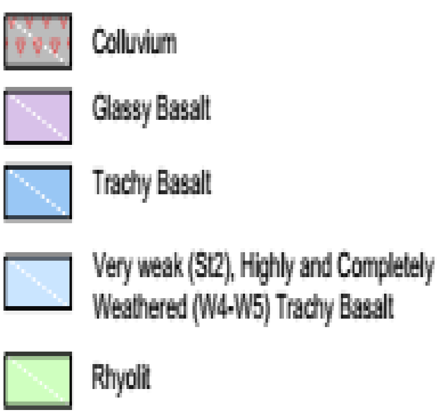
  Strength of Cohesive Soils," Soils and Foundations,
- Terzaghi, K., Peck, R.G., and Mesri, G. (1996). Soil Mechanics in Engineering Practice, 3rd
- Whittaker and Frith ,1990
- Wickham et al (1972) describe a quantitative method for describing the quality of rock mass

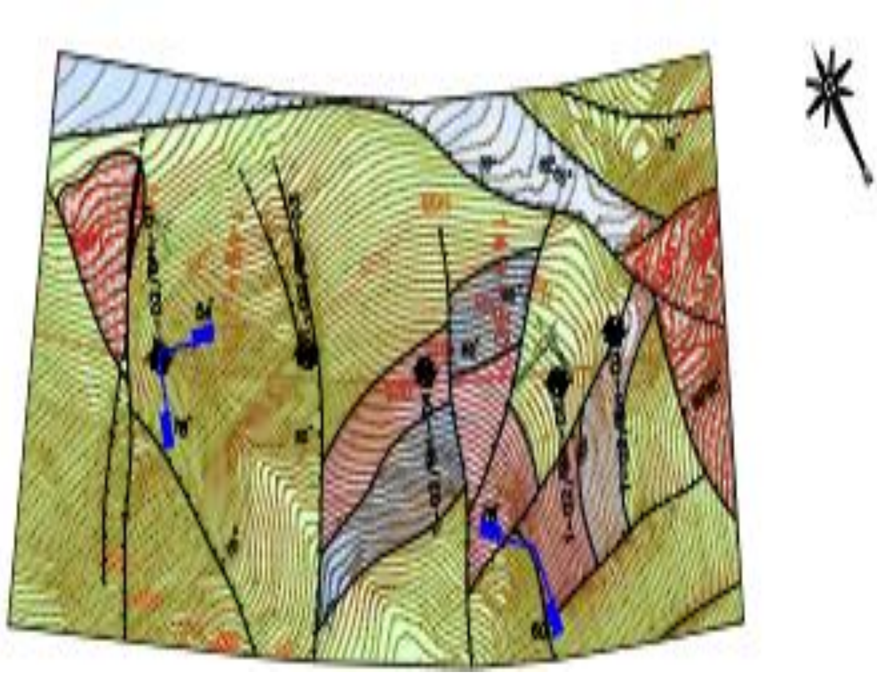
APPENDIX 1

GEOTECHNICAL PLAN AND PROFILE

LEGEND

For geotechnical plan





(Source ERC and AWH railway project office)

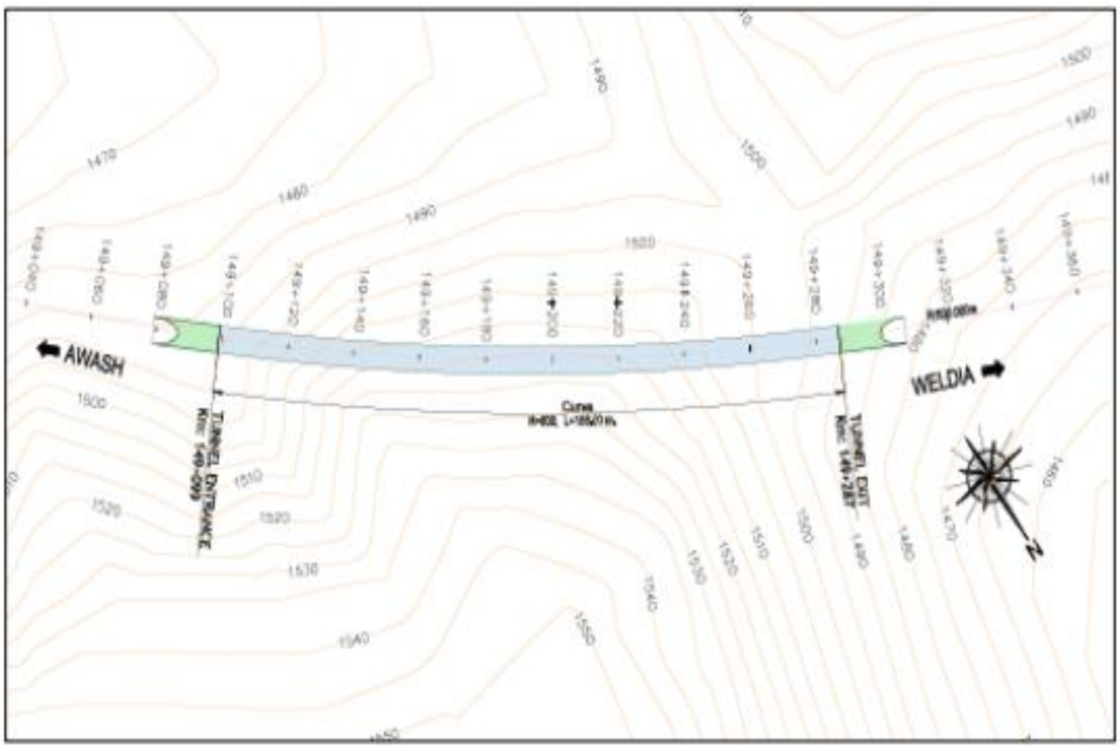


Figure1.3 Layout of Tunnel T-02 (source: ERC and AWH railway project office)

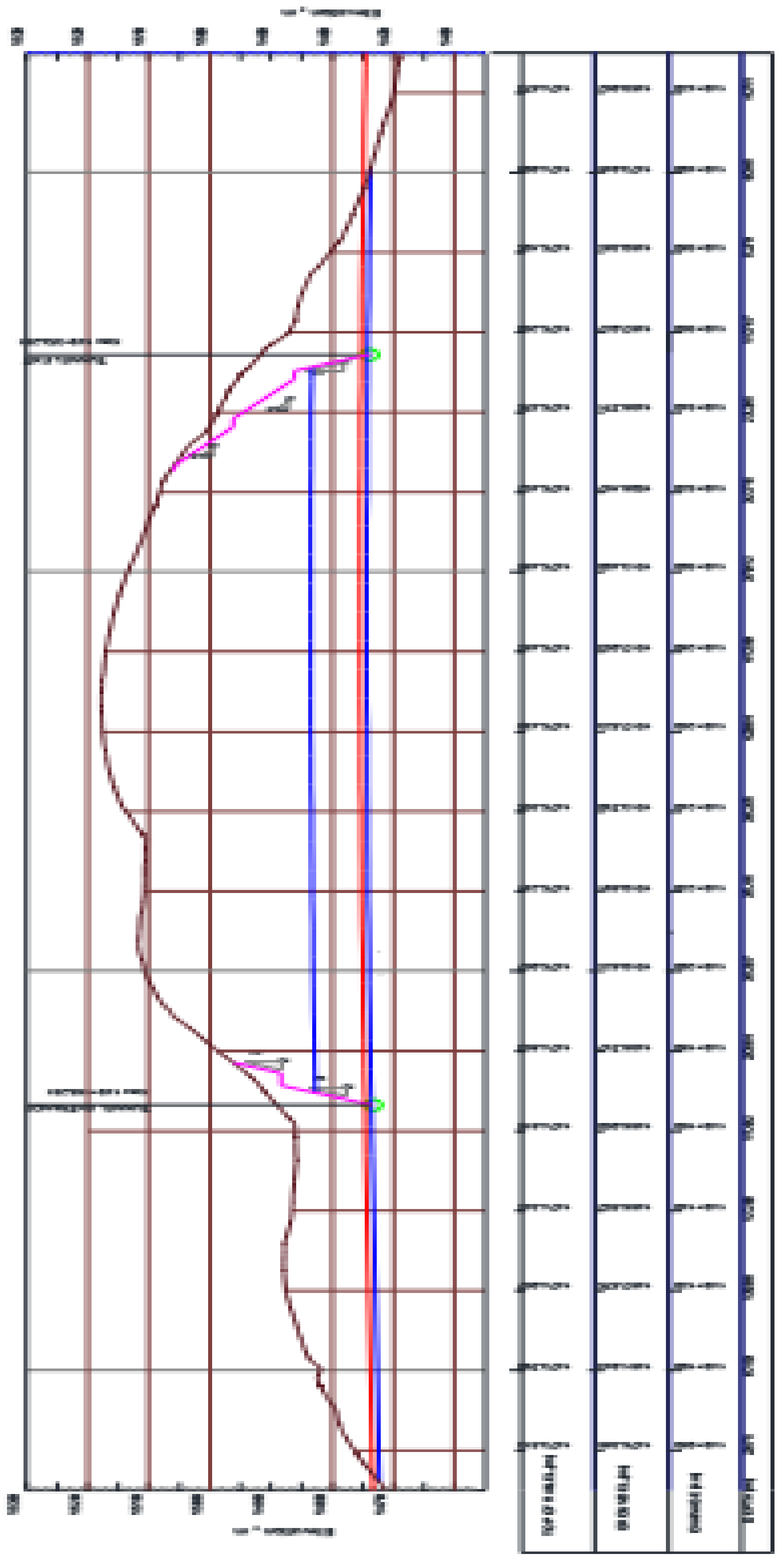
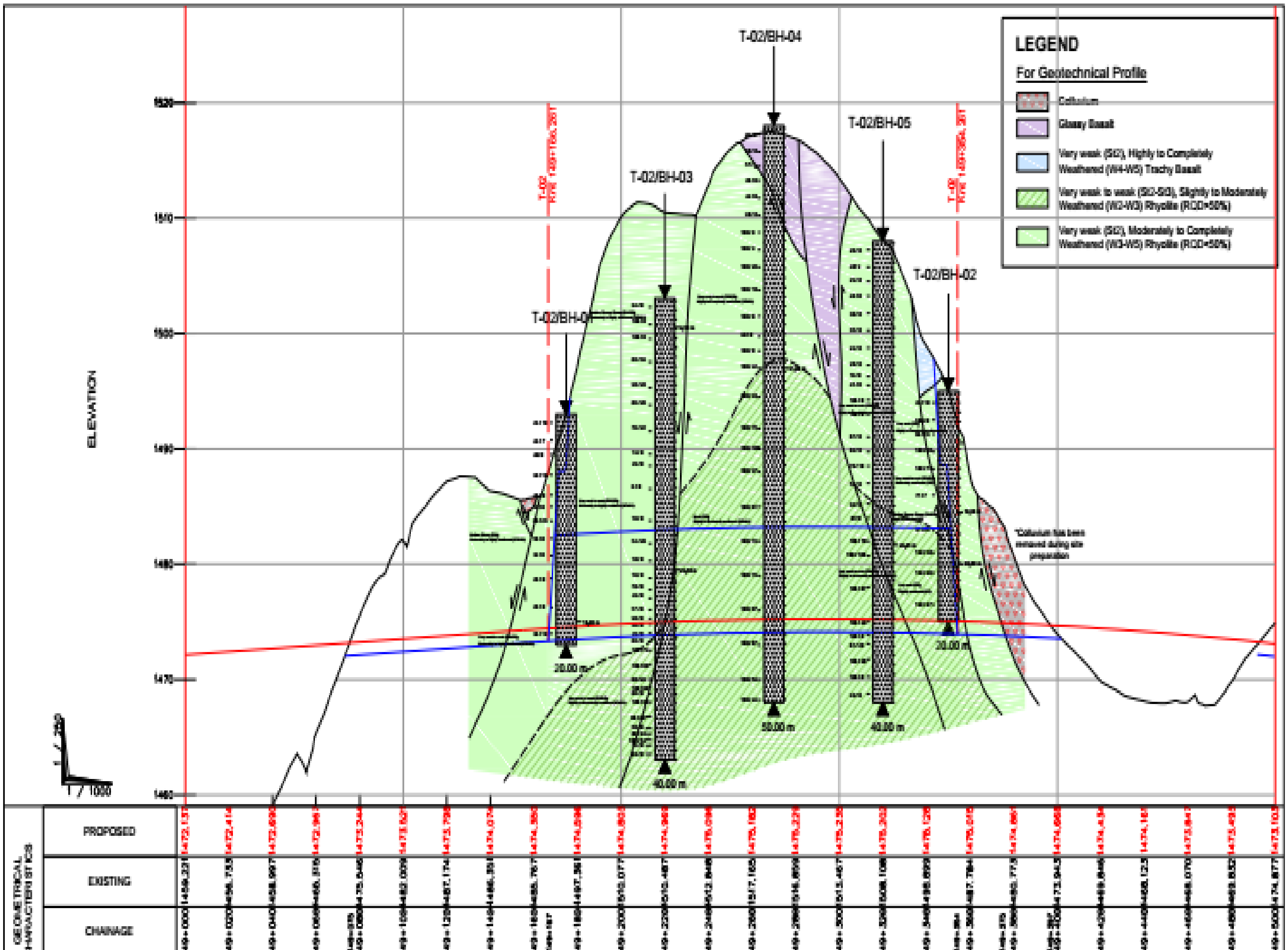


Figure 1.4   Cross-section of tunnel T-02.(Source: ERC and AWH railway project office)



GEOMETRICAL CHARACTERISTICS	REFERENCE COVER (m)	N/A	N/A	15	30	30	35	35	35	15 - 30	N/A	N/A	N/A
GEOLOGY LITHOLOGY	LITHOLOGY (TUNNEL LEVEL)	FILL	RHYOLITE (OPEN CUT)	RHYOLITE (TUNNEL)							RHYOLITE (OPEN CUT)	COLLUVIUM (OPEN CUT)	FILL
	GROUNDWATER CONDITION	–	–	–							–	–	–
GEOMECHANICAL PARAMETERS OF INTACT ROCK	UNIT WEIGHT γ [kN/m³]	N/A	22 / 22	22	23	22	24	24	24	24	22 / 23	N/A	N/A
	UNIAXIAL COMPRESSIVE STRENGTH UCS [MPa]	N/A	20 / 20	5	10	10	15	15	15	15	15 / 20	N/A	N/A
	ELASTIC MODULUS E_{lab} [GPa]	N/A	8,0 / 8,0	2,0	4,0	2,0	6,0	6,0	6,0	6,0	6,0 / 8,0	N/A	N/A
	POISSON'S RATIO ν [-]	N/A	0,28 / 0,25	0,25	0,20	0,20	0,20	0,20	0,20	0,20	0,28 / 0,25	N/A	N/A
ROCK MASS CLASSIFICATION AND DESIGN PARAMETERS	RMR	N/A	20-40 / 30-50	20-40	30-50	20-40	40-60	40-60	40-60	20-40	20-40 / 30-50	N/A	N/A
	GSI	N/A	20 / 25	25	35	25	45	65	45	25	25 / 35	N/A	N/A
	c_m [kPa]	N/A	61 / 75	28	79	56	134	234	134	43	67 / 64	N/A	N/A
	ϕ_m	N/A	32,3 / 35,9	31,3	37	31,3	44	53,3	44	38,8	33,8 / 47,6	N/A	N/A
	E_m [MPa]	N/A	202 / 226	56	160	113	404	1365	404	169	169 / 320	N/A	N/A
	EXCAVATION METHOD		MECHANICAL	MECHANICAL & BLASTING							MECHANICAL		
	NOTES			NO GW EXPECTED, LOCAL SEEPAGE POSSIBLE									

(Source:ERC and AWH railway project office)

APPENDIX 2

SAMPLE OF BOREHOLE LOGS

BOREHOLE NO: T-02/BH-01

CONTRACTOR	EMPLOYER	EMPLOYER'S REPRESENTATIVE
yapı merkezi	ERC Ethiopian Railway Corporation	SYSTRA MD

BOREHOLE LOG

Date Started/Completed	: 28.02.2015/ 04.03.2015
Coord. Y (E)	: 609159,583
Coord. X (N)	: 1132687,798
Elevation (Z)	: 1489,597 m
Location	: KM: 149+175
Equipment/Method	: DS-750/Rotary with water flush
Groundwater Level	: Nil
Casing Length	: - m
Casing Diameter	: 76,00 mm - 89,00 mm
Borehole Depth	: 20,00 m

BOREHOLE NO: T-02/BH-01

(Page 1 / 2)

AWASH - KOMBOLCHA - HARA GEBEYA RAILWAY PROJECT

P:Pressuremeter Test
P*:Pressuremeter Test (Failed)
WPT: Water Pressure Test
WPT*: Water Pressure Test (Failed)

In-Situ Test	Sample Depth (m)	Sample Type	TCR %	SCR %	RQD %
	0,00-1,50	CR	23	10	10
	1,50-3,00	CR	43	40	7
	3,00-4,00	CR	40	35	0
WPT	4,00-6,50	CR	90	75	10
	6,50-7,50	CR	40	0	0
	7,50-8,50	CR	52	18	0
	8,50-10,00	CR	83	60	23
WPT	10,00-11,50	CR	50	38	0
	11,50-13,00	CR	32	30	0
WPT	13,50-15,50	CR	20	15	0

Other column headings: Borehole Depth (m) 0–15; Groundwater Level; 0 - 15 cm; 15 - 30 cm; 30 - 45 cm; N 30; 0 10 20 30 40 50; Soil classification; Soil-Rock Symbol.

Soil-Rock Description

Artificial Fill

0,40

Light Gray BASALT

Medium strong

Moderately to highly weathered

With very closely spaced joints, undulating-rough

FeO stained on joint surfaces

Weathering	Strength	Joint Spacing
W3-W4	St4	S2

SPT: Standard Penetration Test UD: Undisturbed Sample CR: Core Sample SPT*: No recovery UD*: Failed SC: Soil Core Sample

DRILLER	LOGGED BY	CHECKED BY
TUNCAY KOSEM	GOKHAN COLAK	FEHMI ERSAN

BOREHOLE NO: T-02/BH-01((source ERC and AWH railway project office)

CONTRACTOR	EMPLOYER	EMPLOYER'S REPRESENTATIVE
yapı merkezi	ERC Ethiopian Railway Corporation	SYSTRA MD

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Elevation (Z)	: 1489,597 m
Location	: KM: 149+175
Equipment/Method	: DS-750/Rotary with water flush
Groundwater Level	: Nil
Casing Length	: - m
Casing Diameter	: 76,00 mm - 89,00 mm
Borehole Depth	: 20,00 m

BOREHOLE NO: T-02/BH-01

(Page 2 / 2)

AWASH - KOMBOLCHA - HARA GEBEYA RAILWAY PROJECT

P:Pressuremeter Test
P*:Pressuremeter Test (Failed)
WPT: Water Pressure Test
WPT*: Water Pressure Test (Failed)

Borehole Depth (m)	Groundwater Level	In-Situ Test	Sample Depth (m)	Sample Type	0 - 15 cm	15 - 30 cm	30 - 45 cm	N 30	0 10 20 30 40 50	Soil classification	Soil-Rock Symbol	Soil-Rock Description	TCR %	SCR %	RQD %	Weathering	Strength	Joint Spacing
15		WPT	13,50-15,50	CR								Light Gray BASALT	20	15	0			
16–18			15,50-18,00	CR								Medium strong Moderately to highly weathered With very closely spaced joints, undulating-rough FeO stained on joint surfaces	20	15	0	W3-W4	St4	S2
18–20		WPT	18,00-20,00	CR								18,00 Redish Brown, BASALT Very weak to weak Moderately to highly weathered, With very closely spaced joints, undulating-rough With clay content	38	30	10	W3-W4	St2-St3	S2
20												End of Borehole: 20,00 m						

Depth scale: 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

SPT: Standard Penetration Test UD: Undisturbed Sample CR: Core Sample SPT*: No recovery UD*: Failed SC: Soil Core Sample

DRILLER	LOGGED BY	CHECKED BY
TUNCAY KOSEM	GOKHAN COLAK	FEHMI ERSAN

Geotechnical Report, Tunnel T-02 (Km:149+166-149+354) AKH-YMI-DD-TU02X-G-GT-REP-1004-0 04.12.2015 Page 42 of 227

BOREHOLE NO: T-02/BH-01

(SourceERC and AWH railway project office; (site investigation report))

T-O2/BH-01 COREBOX NO:1

T-O2/BH-01 COREBOX NO:2

(Source ERC and AWH railway project office; (site investigation report))

T-O2/BH-01 COREBOX NO:3

T-02/BH-03 COREBOX NO:1

(Source ERC and AWH railway project office; (site investigation report))

T-02/BH-03 COREBOX NO:3

T-O2/BH-02 COREBOX NO:4

(Source ERC and AWH railway project office; (site investigation report))

APPENDIX 3

Figure describing tunnel T-02 project

Appearance of rock mass	Description of rock mass	Suggested value of *D*
	Excellent quality controlled blasting or excavation by Tunnel Boring Machine results in minimal disturbance to the confined rock mass surrounding a tunnel.	$D = 0$
	Mechanical or hand excavation in poor quality rock masses (no blasting) results in minimal disturbance to the surrounding rock mass. Where squeezing problems result in significant floor heave, disturbance can be severe unless a temporary invert, as shown in the photograph, is placed.	$D = 0$ $D = 0.5$ No invert
	Very poor quality blasting in a hard rock tunnel results in severe local damage, extending 2 or 3 m, in the surrounding rock mass.	$D = 0.8$
	Small scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used as shown on the left hand side of the photograph. However, stress relief results in some disturbance.	$D = 0.7$ Good blasting $D = 1.0$ Poor blasting
	Very large open pit mine slopes suffer significant disturbance due to heavy production blasting and also due to stress relief from overburden removal. In some softer rocks excavation can be carried out by ripping and dozing and the degree of damage to the slopes is less.	$D = 1.0$ Production blasting $D = 0.7$ Mechanical excavation

Figure 1 Guideline for estimating the disturbance factor, (source;from Hoek et.al. 2002)

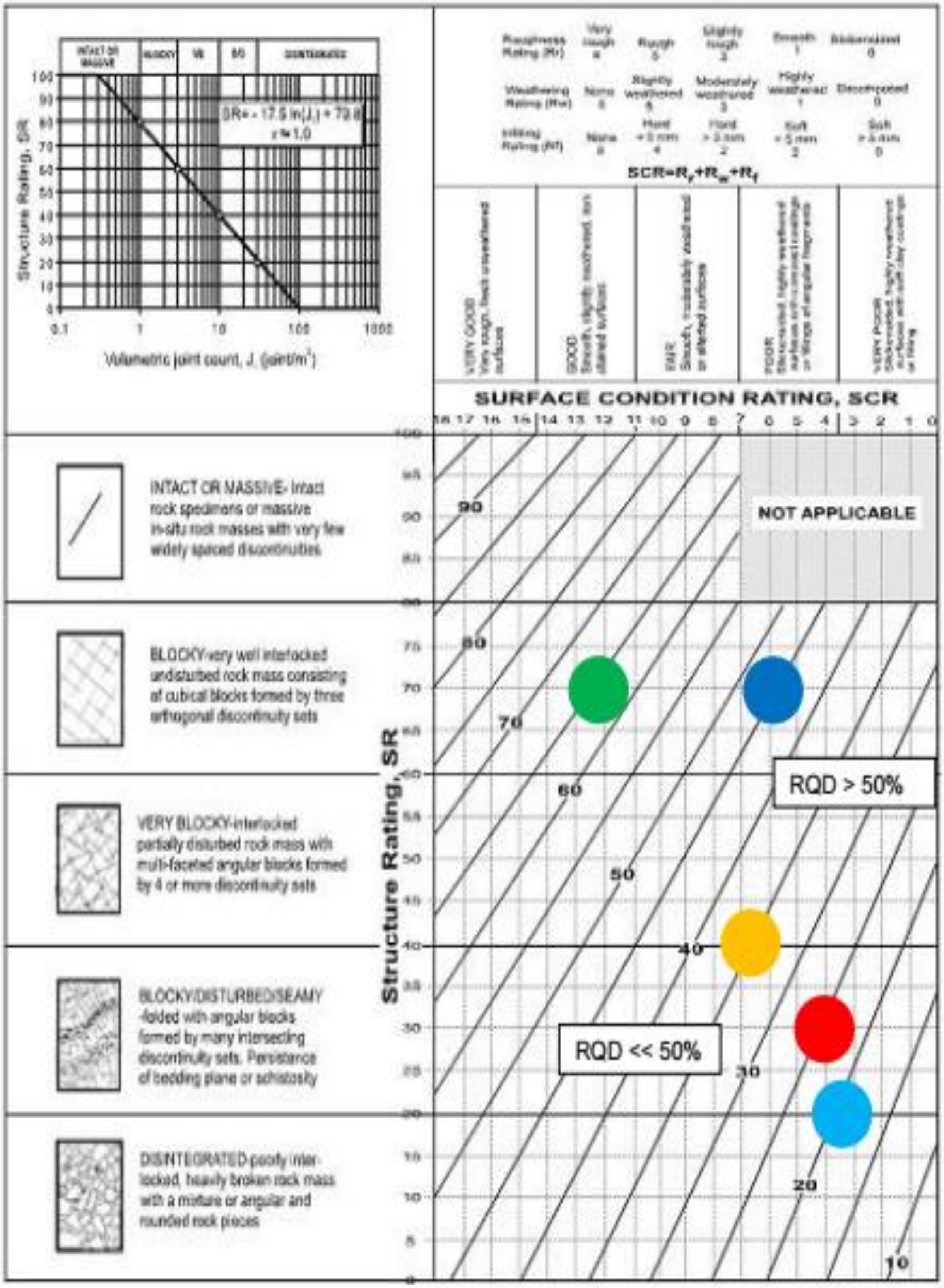
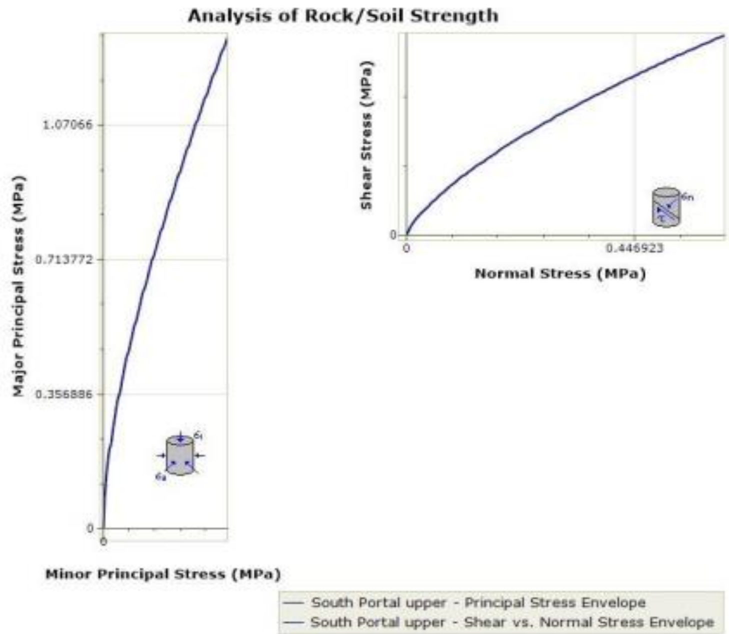

SURFACE CONDITION RATING, SCR
NOT APPLICABLE
RQD > 50%
RQD << 50%
Structure Rating, SR
INTACT OR MASSIVE- intact rock specimens or massive in-situ rock masses with very few widely spaced discontinuities
BLOCKY-very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets
VERY BLOCKY-interlocked partially disturbed rock mass with multi-faceted angular blocks formed by 4 or more discontinuity sets
BLOCKY/DISTURBED/SEAMY -folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding plane or schistosity
DISINTEGRATED-poorly inter-locked, heavily broken rock mass with a mixture or angular and rounded rock pieces

Figure 2 GSI elevation of rock units in tunnel T-02 (colored solid circles denote the selected GSI valves)

(Source ERC and AWH railway project office; (site investigation report))



South Portal upper	
Hoek Brown Classification	
intact uniaxial compressive strength	20 MPa
GSI	20
mi	25
disturbance factor	0.8
intact modulus	8000 MPa
modulus ratio	400
Hoek Brown Criterion	
mb	0.214
s	5.443e-006
a	0.544
Failure Envelope Range	
application	slopes
sig3max	0.339 MPa
unit weight	0.022 MN/m3
slope height	20 m
Mohr Coulomb Fit	
cohesion	0.061 MPa
friction angle	32.37 deg
Rock Mass Parameters	
tensile strength	-5.093e-004 MPa
uniaxial compressive strength	0.027 MPa
global strength	0.946 MPa
modulus of deformation	202.11 MPa

Figure 3 analysis of rock mass parameters for south portal area upper layer (149+075-149+167)(Source ERC and AWH railway project office; (site investigation report))

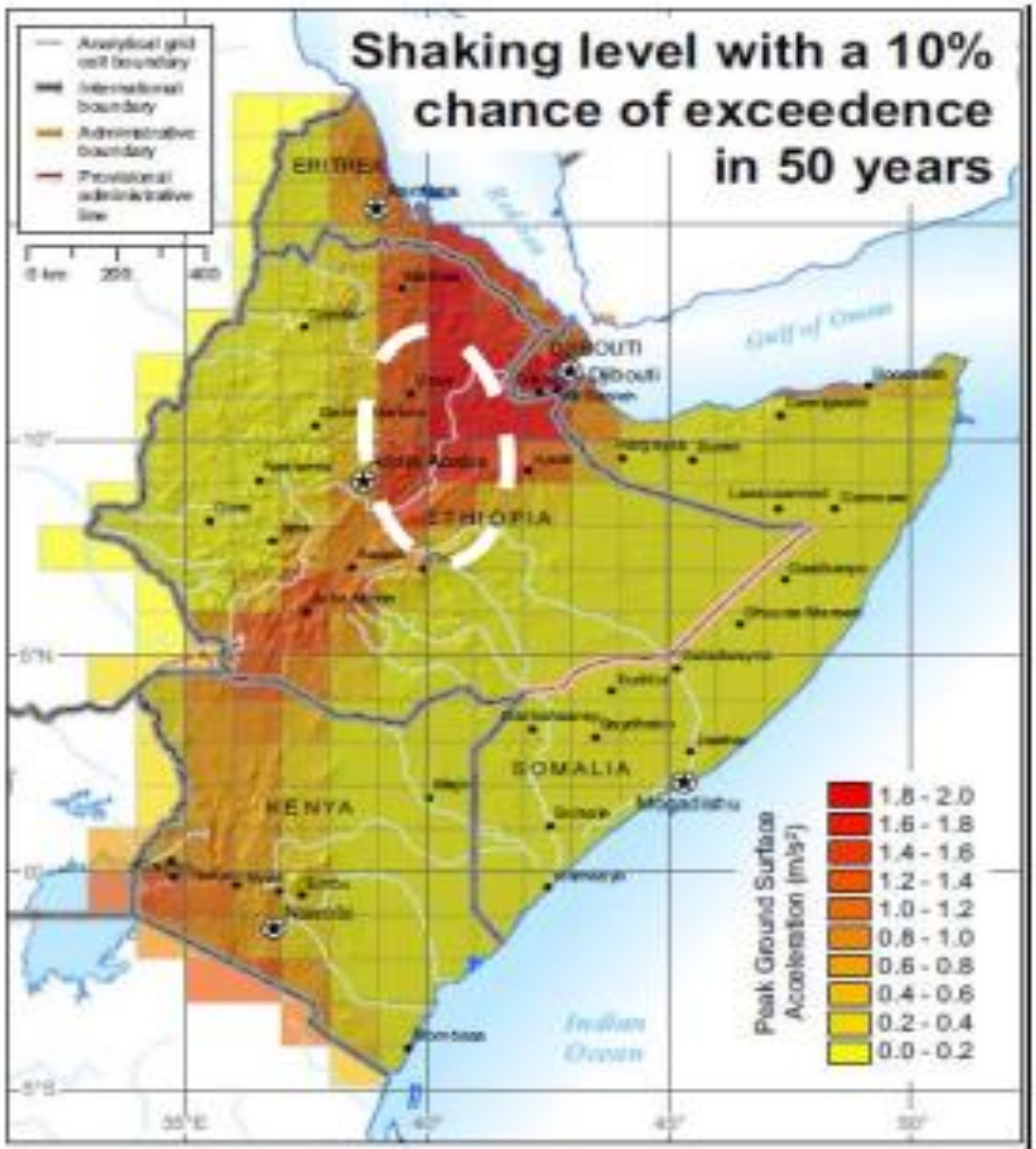


Figure 4.seismicity of the Horn of Africa

(From the http reference given above; the bounded area is approximate project site)

APPENDIX 4

Summary of table from geotechnical investigation and test sample

(All Table Source:ERC and AWH railway project office;

(Site investigation report))

Table 1. The coordinates and evaluations of the boreholes drilled for tunnel T-02

(Source ERC and AWH railway project office; (site investigation report))

Borehole no.	**Chain age (km)**	**Depth (m)**	**Easting**	**Northing**	**Elevation (m)**
T-02/BH-01	149+175	20.0	609159.583	1132687.798	1489.597
T-02/BH-03	149+220	40.0	609072.729	1132751.945	1505.985
T-02/BH-04	149+270	50.0	609040.052	1132780.46	1512.44
T-02/BH-05	149+320	40.0	609002.339	1132810.712	1508.294
T-02/BH-01	149+350	20.0	608979.250	1132814.051	1498.873

Table 2 The results of the water pressure tests in borehole drilled for tunnel T-02.

(Source ERC and AWH railway project office; (site investigation report))

Borehole (km)	Test section (depth, m)	lugeon
T-02/BH-01(149+175)	3.50-6.50	79.84
,,	9.50-11.50	59.88
,,	13.50-15.50	79.84
	18.00-20.00	59.88
T-02/BH-03(149+220)	26.50-29.50	53.23
	31.00-34.00	12.23
	37.00-34.00	53.23
T-02/BH-04(149+270)	23.00-25.00	1.05
	25.50-28.50	0.85
	31.50-34.50	2.29
	34.50-.7.50	3.05
	37.50-40.50	0.86
	40.50-43.50	0.87
	43.50-46.50	0.44
	47.00-50.00	0.79
T-02/BH-02(149+350)	4.50-7.50	53.23
	11.50-13.50	1.99
	15.00-17.00	0.72
	18.00-20.00	0.90

Table 3the results of laboratory tests for rock samples

(Source ERC and AWH railway project office; (site investigation report))

sample		Unit weight	Unconfined compressive strength – rock (ucs)	Modulus of elasticity	Poisson's ratio	Point load strength index
borehole	Depth (m)	γn (g/cm^3)	$\sigma c\ (mpa)$	E(Gpa)	υ	$IS_{50}(50)$
T2/BH-01	0.00-3.00	2.508				4.61
T2/BH-01	3.00-6.00	2.501				3.48
T2/BH-01	6.00-9.00	2.479				3.93
T2/BH-01	9.00-12.00	2.54				4.68
T2/BH-01	12.00-15.00	2.52				3.19
T2/BH-01	15.00-18.00	2.559				3.47
T2/BH-01	18.00-20.00	1.933				0.17
T2/BH-03	0.00-2.50	2.376				2.83
T2/BH-03	2.50-5.00	2.149				0.05
T2/BH-03	5.00-7.50	2.106				0.17
T2/BH-03	7.50-10.00	1.922				0.09
T2/BH-03	10.00-10.30	2.013	2.17			
T2/BH-03	10.30-10.60	2.013				0.37
T2/BH-03	10.60-10.80	1.857				0.24
T2/BH-03	11.00-14.00	1.983				0.32
T2/BH-03	20.50-23.50	2.471				0.67
T2/BH-03	23.50-26.50	2.457				0.37
T2/BH-03	26.50-30.00	2.510				0.22
T2/BH-03	30.00-31.10	2.547				0.65
T2/BH-03	30.10-31.50	2.562				0.70
T2/BH-03	3.50-3.70	2.659				0.23
T2/BH-03	32.30-32.50	2.632				0.39
T2/BH-03	32.50-32.90	2.420				0.48
T2/BH-03	33.50-33.90	2.486	4.76			
T2/BH-03	34.50-34.70	2.465				0.15
T2/BH-03	35.60-35.80	2.482				
T2/BH-03	35.80-38.00	2.535				0.56
T2/BH-03	38.00-40.00	2.547				0.09
T2/BH-04	9.00-12.00	2.528				0.07
T2/BH-04	12.00-15.00					0.12
T2/BH-04	15.00-18.00					0.06
T2/BH-04	18.00-21.00					0.06
T2/BH-04	21.00-21.30					
T2/BH-04	21.50-21.90					
T2/BH-04	22.20-22.40					
T2/BH-04	22.50-22.80					
T2/BH-04	23.10-23.50					
T2/BH-04	24.30-24.60					
T2/BH-04	25.00-25.50					
T2/BH-04	26.50-26.80	2.531	18.08			
T2/BH-04	27.60-27.90	2.602	20.91	2.16		

T2/BH-04	28.50-28.80	2.515	20.99			
T2/BH-04	29.40-29.60	2.497	19.99	1.73		
T2/BH-04	30.20-30.50	2.466	12.87			
T2/BH-04	31.30-31.50	2.451	23.90	1.65		
T2/BH-04	32.50-32.90	2.508	19.95			
T2/BH-04	34.50-34.80	2.686	27.88	2.77		

Table 4relationship between Lugeon, permeability and condition of rock mass discontinuities

(Source ERC and AWH railway project office; (site investigation report))

Lugeon range	Classification	Hydraulic conductivity range (m/s)	Condition of rock mass discontinuities
<1	Very low	$<1*10^{-7}$	very tight
1-5	Low	$1*10^{-7}$ -6 $*10^{-7}$	Tight
5-15	Moderate	$6*10^{-7}$ - 2 $*10^{-6}$	Few partly open
15-50	Medium	$2*10^{-6}$ - $6*10^{-6}$	Some open
50-100	High	$6*10^{-6}$ - $1*10^{-5}$	Many open
>100	Very high	$>1*10^{-5}$	Open closely spaced / voids

Table 5. The evaluation of p- wave velocities with respect to the tunnel

(Source ERC and AWH railway project office; (site investigation report))

Seismic survey line	Location	Top-of-rails level below G.L (m)	Max. p wave velocity expected at top-of-rails level (m/s)	P wave penetration achieved (m)*
1	S portal	13	2000	16
2	Tunnel (149+280)	42	>2500	16
3	Tunnel	24	>2200	16
4	N portal	13	1300	16

Table 6proposed tunnel / portal design parameters

(Source ERC and AWH railway project office; (site investigation report))

				Rock mass parameters			
Zones	Lithology	Chain age	γ (kN/m^3)	c' (kpa)	$ø'$ (Deg.)	ν'	E'
South portal upper	Rhyolite	149+075-149+167	22	61	32.3	0.28	202
South portal lower	Rhyolite	149+075-149+167	22	75	35.9	0.25	226
Tunnel zone 1	Rhyolite	149+167-146+180	22	28	31.3	0.25	56
Tunnel zone2	Rhyolite	149+180-149+210	23	79	37.0	0.20	160
Tunnel zone 3	Rhyolite	149+210-149+235	22	56	31.3	0.20	113
Tunnel zone 4	Rhyolite	149+235-	24	134	44.0	0.20	404

		149+255					
Tunnel zone 5	Rhyolite	149+255-149+265	24	234	53.3	0.20	1365
Tunnel zone 6	Rhyolite	149+265-149+295	24	134	44.0	0.20	404
Tunnel zone 7	Rhyolite	149+295-149+354	24	43	38.8	0.20	169
North portal upper	Rhyolite	149+354-149+375	22	67	33.8	0.28	169
North portal lower	Rhyolite	149+354-149+375	22	64	47.6	0.25	320

Table 7 The vs (30) values computed, and the recommended design ground type and soil factor are as follows

Area	Survey line	km	Ground elevation at seismic line (m)	Seismic survey penetration depth (m)	Vs(30) (m/s)*	Ground type	Top of rail elevation (m).	Tunnel depth below G.L (M)	S wave velocity at tunnel level (m/s)
South portal	1	149+135	1487	24	526	B	1474	13	600
Tunnel	2	149+280	1517	30	600	A	1475	42	>1000
	3	149+340	1499	22	749	A	1475	24	>1100
North portal	4	149+365	1488	28	548	B	1475	13	

*it has not been always possible to achive 30m penetration in the surveys due to limited spread lengths. Ground types for portals are estimated with respect to the ground surface. For the tunnel body,S wave velocity at the tunnel level has been taken in to consideration

APPENDIX 5

Photo depicting same feature of Tunnel T-02 Project and Type of equipment used

(Source: AASTU Geotechnical student (2007 entry)

During Awash – weldya tunnel project site visits)

Photo 1, view of the south portal area of tunnel T-02

(Source ERC and AWH railway project office; (site investigation report))

Photo 2 view of the north portal area of tunnel T-02 (trachybasalt overlying rhyolite at the portal location)
(Source ERC and AWH railway project office; (site investigation report))

Photo 5 shot Crete machine done in temporary lining

(Source**:** AASTU 2007 E.Centry Geotechnical student (during project site visits))

Photo 6 rock bolt materials used in T-02

(Source**:** AASTU 2007 E.Centry Geotechnical student (during project site visits))

Photo 7permanent lining and rock bolt materials used in T-02

(Source: AASTU 2007 E.Centry Geotechnical student (duringTunnel projectsite visits))

Photo 8 Tunnel drill machine used in Awash – kombolcha tunnel project

(Source: AASTU 2007 E.Centry Geotechnical student (duringTunnel projectsite visits))

Photo 9 Tunnel drill machine used in Awash – kombolch tunnel project

(Source**:** AASTU 2007 E.Centry Geotechnical student (duringTunnel project site visits))

Photo 10 shot Crete machine used in T-02

Photo 11tunnel Portal back filling work

(Source**:** AASTU 2007 E.Centry Geotechnical student (during project site visits))

Photo 12 Drill and mechanical excavation equipment

Photo 13water proofing material at portal area

(Source**:** AASTU 2007 E.Centry Geotechnical student (during Tunnel project site visits))